BROOKHAVEN
NATIONAL LABORATORY

BNL-79911-2008-CP

Measurement of ion beam from laser ion source for RHIC EBIS

Takeshi Kanesue
Kyushu University, Fukuoka 819-0395, Japan

Jun Tamura
Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8550, Japan

Masahiro Okamura
BNL, Upton, NY 11973, USA

Presented at the 11[th] Biennial European Particle Accelerator Conference (EPAC 2008)
Genoa, Italy
June 23-27, 2008

Collider-Accelerator Department

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

DISCLAIMER

MEASUREMENT OF ION BEAM FROM LASER ION SOURCE FOR RHIC EBIS

Takeshi Kanesue, Kyushu University, Fukuoka 819-0395, Japan
Jun Tamura, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8550, Japan
Masahiro Okamura, BNL, Upton, NY 11973, U.S.A.

Abstract

Laser ion source (LIS) is a candidate of the primary ion source for the RHIC EBIS. LIS will provide intense charge state 1+ ions to the EBIS for further ionization. We measured plasma properties of a variety of atomic species from C to Au using the second harmonics of Nd:YAG laser (532 nm wave length, up to 0.5 J / 6 ns). Since properties of laser produced plasma is different from different species, laser power density for singly charged ion production should be verified experimentally for each atomic species. After plasma analysis experiments, Au ions was extracted from plasma and emittance of the ion beam was measured using a pepper pot type emittance monitor.

INTRODUCTION

The RHIC-EBIS is the future heavy ion injector for Relativistic Heavy Ion Collider and NASA Space Radiation Laboratory [1]. The low charge state, low emittance and high ion yield laser ion source (LIS) using a high power Nd:YAG laser with a defocused laser beam is being studied as the primary ion source for the RHIC-EBIS [2]. To provide stable pure singly charged ions of various species, laser irradiation conditions are required to be controlled well. The LIS produces ions by pulsed high power laser irradiation onto a solid state target. The target is rapidly heated, vaporized and becomes plasma which is called laser ablation plasma then the plasma expands adiabatically perpendicular to the target surface. Properties of Laser ablation plasma such as charge state distribution, current and ion energy mainly depends on laser power density. By decreasing the power density, LIS can be optimized for singly charged, low energy ion production which is suitable to provide seed ions for charge bleeding system such as EBIS. We also confirmed the extracted beam emittance from Au plasma.

SINGLY CHARGED ION PRODUCTION

We surveyed the laser power density on the target to produce charge state 1+ ion dominant plasma. The arget species of C, Al, Si, Fe, Fe, Ta and Au were used for this experiment.

Experimental setup

Figure 1 shows a schematic view of our experimental setup to measure the plasma total current and charge state distribution. We used a second harmonics of Nd:YAG laser (0.5 J / 6 ns). A laser light was transported by three flat mirrors to a convex lens. We used three lenses which had focal length of 800 mm, 1000 mm and 1500 mm, respectively to change a laser spot size on the target. The lens was placed on an optical rail fixed parallel to the laser path to control a spot size too. These lenses and optical rail allowed us to control laser power density ranging from 10^8 W / cm^2 to over 10^{10} W / cm^2 during the experiment. The laser light was focused onto the target with an incident angle of about 6 degrees. The target plate was attached to a 3D manipulator to provide fresh surface when it was damaged. The target surface was aligned perpendicular to measurement line. The laser ablation plasma generated by a laser shot was expanded adiabatically normal to the surface. A Faraday cup (FC) was placed at 1.74 m far from target to measure plasma total current which had an aperture of 10 mm diameter and a mesh of which transmission was 85 % with a bias voltage of -2.5 kV to suppress secondary electron and extract ions from plasma. The charge state distribution was measured using a cylindrical 90 degrees electrostatic ion analyzer (EIA) and a secondary electron multiplier (SEM) located downstream of the FC. SEM was biased -3.5 kV. Ion signal from each charge state was obtained by scanning EIA applied voltage until ion signal disappeared. The signal was enhanced and detected by the SEM of which multiplicity was different from ion energy, charge state and ion species. We calibrated ion signal by comparing the sum of each charge state signal multiplied by its charge state to FC total current.

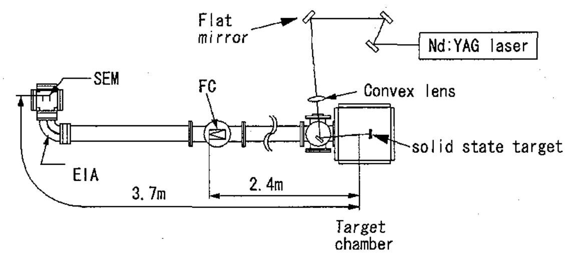

Figure 1: schematic view of experimental setup

Results

The relationship between the power density and plasma total current was measured using FC. The laser power density was controlled by changing laser spot size on the target. The laser condition was scanned from high power density to low power density until plasma signal vanished. As decreasing laser power density, firstly total yield increased since the laser spot size is increased. And a peak yield appeared, then it started to decrease and plasma signal became zero finally. This descend was

Work performed under contract No. DE-AC02-98CH10886 under the auspices of the United States DOE and with the support of RIKEN (Japan).

caused by less plasma emission from the unit target surface area although laser irradiated area became larger.

These results obtained using the FC could contain multiple charge state, so we analyzed charge state distribution of the plasma. Figure 2 shows the ratio of charge state 1+ ions as a function of a laser power density. In this range, only charge state 1+ and 2+ ions were detected. We defined that laser power density where 95 % of particles were singly charged ions was threshold for charge state 1+ ion production. Below this limit, plasma properties such as the number of particles, peak current and pulse duration were obtained based on FC signal. Figure 3 shows the plasma parameters as a function of laser power density scaled at 1 m with 1 cm^2 extraction area using the relationship [2]:

$$I \propto L^{-3} \qquad (1)$$
$$\tau \propto L$$

, where I, τ and L represent a current density, pulse duration and plasma drift length, respectively. The LIS performance can be controlled by the laser power density, the drift distance and the extraction aperture using these relationships. Based on the obtained data, a dedicated LIS for the primary ion source of the RHIC-EBIS was designed which satisfy the requirement for number of particles. Table 1 shows the particle number required by the RHIC-EBIS and the corresponding LIS conditions for C, Si, Fe and Au. Extraction aperture of 30 mm diameter was considered for this design. The detail of particle requirement is shown in [3]. LIS was successfully optimized for singly charged ion production and it was confirmed that LIS can be used as an external ion source for the RHIC EBIS.

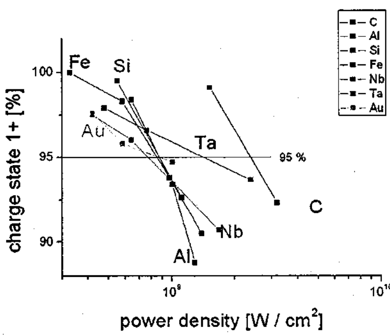

Figure 2: Percentage of singly charged ions inside plasma.

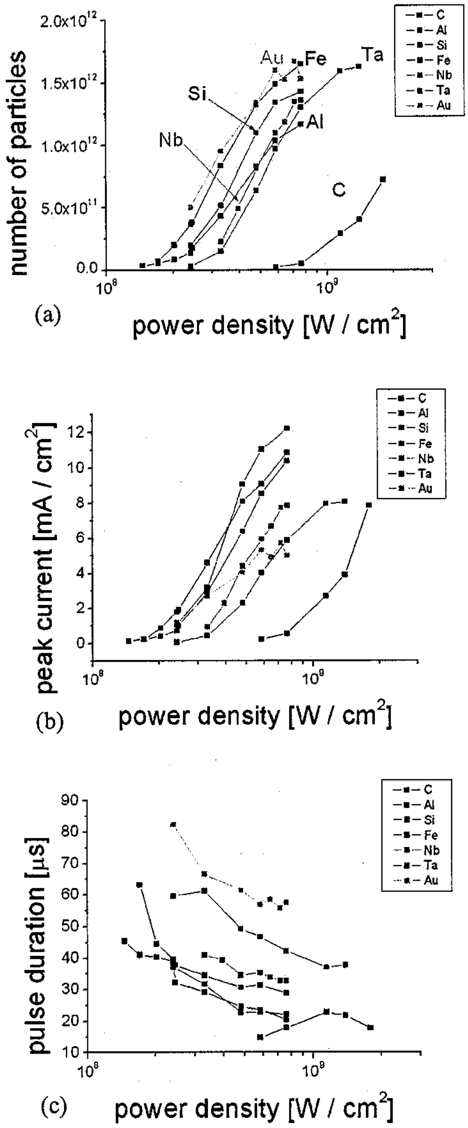

Figure 3: Number of particles (a), peak current (b) and pulse duration (c) of the plasma scaled at 1 m with 1cm^2 aperture below threshold for charge state 1+ ion production.

Table 1: LIS design to satisfy the requirements for primary ion source for the RHIC-EBIS in case of 30 mm extraction aperture.

	Required particle for LIS	Power density[W / cm2]	Drift distance [m]	Peak current[mA]
C	1.15E+12	3.2E+9	2.5	4700
Si	4.26E+11	4.0E+8	2.65	920
Fe	2.40E+11	2.6E+8	3.6	325
Au	1.72E+11	2.0E+8	3.6	116

EMITTANCE MEASUREMENT

Emittance of Au ion beam was measured using the pepper pot emittance monitor [4]. For this experiment, ion source test bench was modified to extract ions from plasma and to transport them to the pepper pot. Laser power density and extraction condition was chosen to achieve sufficient particles as a primary ion source although condition was not the same written in Table 1 due to the setup limitation.

Experimental setup

Laser power density of $1.7\times10^{8}\ \mathrm{W\ /\ cm^2}$ was used for this experiment. The Faraday cup and the EIA were removed and an ion extraction column, a gridded lens to focus ion beam and the pepper pot emittance monitor were installed. The extraction column which consisted of a 25.4 cm long insulator, extraction electrode with 18 mm aperture at the entrance of the insulator, grounded electrode with 70 mm aperture at the other side and intermediate electrode which has 36 mm aperture was placed 1.6 m far from the target. The intermediate electrode was movable along the beam axis. At the downstream of the insulator, there was the girded lens which had a mesh and ring electrodes on both sides of the mesh. The beam aberration can be minimized by applying independent voltage to the mesh and the ring. The pepper pot was located at a distance of 2.4 m far from the target. Ion beam current was monitored using a pepper pot mask which is a metal screen with small holes attached in front of emittance monitor system. The mask was biased to 150 V to suppress secondary electrons. Target, Target chamber and plasma drift chamber was biased to 16 kV to extract ions from plasma.

Result

Plasma drifting length and extraction aperture were 1.6 m and 18 mm as mentioned above. The number of particles, the peak current and the pulse duration of the extracted beam were calculated to 1.9×10^{11}, 0.28 mA and 110 μs in this condition. The position and applied voltage of intermediate electrode and gridded lens applied voltage were investigated to transport ions at peak current and half current with good transmission using Kobra 3 code [5]. The intermediate electrode was set at 17 cm upstream from entrance of insulator and was biased to 0 kV, based on the simulation. The emittance of Au beam was measured with these conditions.

The gridded lens voltage was optimized by monitoring the ion current and to minimize emittance value. Since detected current pulse shape was matched accurately to the predicted shape which was scaled form the plasma experiment result, we assume that most of ions were extracted and transported to the pepper pot without beam loss. Peak current of extracted ion signal was 0.30 mA as predicted.

Figure 4 shows a measured horizontal phase space processed by software which was developed for the pepper pot. Normalized RMS emittance was 0.025 π mm mrad. This value is comparable to the Hollow cathode ion source (HCIS) used as the primary ion source for the RHIC-EBIS test stand although the current from the HSIS was typically several tens of micro amperes which is about a order of magnitude lower than that of LIS.

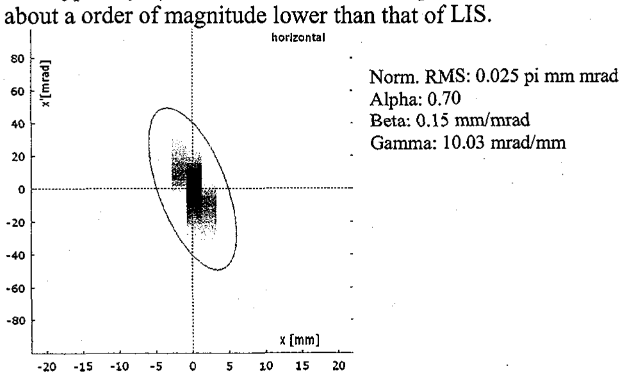

Figure.4: Measured horizontal phase space using Au target with 16 kV extraction.

CONCLUSION

Charge state distributions of C, Al, Si, Fe, Nb, Ta and Au was studied for a singly charged ion production by adjusting laser power density on the target. The obtained LIS performance satisfied the requirements for use of a primary ion source for the RHIC-EBIS from the view point of the number of the particles. The emittance of Au ion beam with 16 kV extraction voltage was measured using the pepper pot. The measured normalized RMS emittance was 0.025 π mm mrad which is comparable to a hollow cathode ion source which is used as a primary ion source for the RHIC-EBIS test stand. It was verified that the LIS can be used as a primary ion source for the RHIC-EBIS.

ACKNOWLEDGEMENT

We are grateful to supports of E. Beebe and A. Pikin of Brookhaven National Laboratory.

REFERENCES

[1] J. Alessi, et. al., "HIGH PERFORMANCE EBIS FOR RHIC", PAC07, Albuquerque, 2007, p3782.
[2] B. Sharkov and S. Kondrashev, "MATCHING OF THE INTENSIVE LASER ION SOURCE TO THE RFQ ACCELERATORS", PAC96, Barcelona, 1996, p1550.
[3] T. Kanesue, J. Tamura and M. Okamura, "Feasibility study of a laser ion source for primary ion injection into the RelativisticHeavy Ion Collider electron beam ion source", Rev. Sci. Instrum. 79 (2008) 02B102.
[4] Brookhaven National Laboratory internal report
[5] P. Spadtke and C. Muhle, "Simulation of ion extraction and beam transport", Rev. Sci. Instrum. 71 (2000) 820.